USING VERY SHORT WRITING TASKS TO PROMOTE UNDERSTANDING IN CHEMISTRY

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ABSTRACT
Writing promotes deeper learning and critical thinking and can assist in knowledge retention, yet students write very little in lectures and tutorials. Very short and informal writing tasks requiring students to explain, describe and summarise their understanding in 1 or 2 sentences have been introduced into chemistry lectures and tutorials as part of our active learning activity toolkit. Development of writing skills is the responsibility of each discipline and every level of a degree and these tasks are used regularly throughout the semester to encourage students to use writing as a way of clarifying ideas and learning new concepts.

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INTRODUCTION
Writing assignments can help students improve their conceptual understanding, clarify their ideas and develop their critical thinking skills. Regular writing tasks promote deep learning and active engagement in their studies. They also provide students with the opportunity to build their own arguments in their own words and to learn from their peers. Science has its own language and reading and presenting are not enough for students to develop fluency in its use.

The ability to write well is, of course, an extremely important graduate attribute. The graduate attributes at most universities refer to communication skills. Graduates of The University of Sydney, for example, “value communication as a tool for negotiating and creating new understanding, interacting with others, and furthering their own learning” (The University of Sydney, 2004). The Faculty of Science graduate attributes specifically mention writing skills: its graduates “write and speak effectively in a range of contexts and for a variety of different audiences and purposes” (The University of Sydney, 2004). As probably *all* graduates will need to write in their working lives, it is imperative that students practice and improve their writing continually during their undergraduate studies.

Despite the recognised importance of writing, many students do no or very little writing at all during a semester. It is not uncommon for students in our classes to take no notes at all during lectures. Indeed, some students do not come equipped with a pen or an electronic device capable of recording their own notes. Although some lecturers lament this change, some lecturing styles promote it. In many classes, the lecture centres around the pre-written words and images projected onto the screen, either live or as a recording.

Before the widespread incorporation of electronic presentations, lecturers would cover blackboards with notes that students would dutifully copy. Although this physical act of copying might promote a somewhat more active engagement than watching a screen, it still relies on the passive transmission of knowledge rather than construction of understanding. As a half way house, some lecturers deliberately leave gaps in their handouts for students to complete during class. Indeed, this tactic is often recommended in teaching seminars as an easy way of promoting attendance and engaging students in class. The gaps sometimes cover a key definition, a derivation or a model answer to a problem. These gaps, however, are almost always filled in by students copying what the lecturer presents. It is, perhaps, not surprising that the use of gaps is commonly seen as a purely artificial device by students, particularly by those who are not confident or quick enough to copy the words and symbols on the screen.

In many large first year subjects, examinations are dominated by or completely constructed from multiple choice questions. Where some short answer questions are included, these are often problem-based requiring equations and numerical responses. As assessment drives learning for many students, this may further convey the message that writing is not valued or valuable. Thus, some students may completely avoid serious writing for the whole semester.

In many science and in most chemistry courses, writing assignments are reserved for laboratory reports. Much effort is used to develop students' ability to write in the formal style expected in the discipline and to convey results and conclusions in a scientific way (see, for example, Drury and Jones, 2007). Writing laboratory reports are important as a stepping stone to writing academic papers and for formally reporting scientific results according to the rules of science and of the discipline. They are designed to communicate results and conclusions to a specific audience. They can also be used to develop skills in scientific inquiry through an understanding of the scientific method and the need to form arguments around evidence (Keys, Hand, Prain, & Collins, 1999; Burke, Greenbowe, & Hand, 2006). Whilst the laboratory report may shift to an online or collaborative task (Taylor, 2006), it should continue to have a central role in our courses. Unfortunately, time and financial pressures often mean that the number of reports that many students complete may be lower than is optimal, particularly in first year courses.

'Writing Across the Curriculum' (WAC) programs were developed in North America during the 1980s as a response to the perception that students were not regularly writing and that the writing ability of graduates was deteriorating. The central philosophy of these programs is that "writing is the responsibility of the entire academic community" and that "writing must be integrated across department boundaries" (The WAC Clearinghouse). Courses that integrate WAC seek to use formal and informal writing tasks continually, at all stages of a degree. By doing this, students become used to writing as a integral part of their studies and use it to learn material, improve critical thinking and understanding and to develop as independent learners (Anson, 2002). In the WAC system, writing laboratory reports is an example of a 'Writing in the Disciplines' (WID) task, as it involves the development of discipline specific conventions, whereas short and informal writing activities designed to promote thinking are termed 'Writing to Learn' (WTL) tasks.

Over recent years, chemistry educators in Australia have been involved through the 'Active Learning in University Science' (ALIUS) group in a sustained effort to establish a new direction in learning and teaching (Bedgood, Yates, Buntine, Pyke, Lim, Mocerino, 2008; Bedgood, Yates, Buntine, Pyke, Lim, Mocerino, Zadnik, Southam, Bridgeman, Gardiner, & Morris, 2010a, 2010b; Bedgood, Mocerino, Buntine, Southam, Zadnik, Pyke, Lim, Morris, Yates, Gardiner, & Bridgeman, 2010). As part of this, active learning techniques for large classes have now become fully integrated into lectures and tutorials in first and some second year chemistry at the University of Sydney. In particular, we have adapted the 'Process Orientated Guided Inquiry Learning' (POGIL) approach widely used in North America (Moog & Spencer, 2008) to our context. Our version of this approach involves the use of worksheets that seek to guide students towards building their own understanding of concepts and ideas.

In place of our traditional didactic lectures, these are now broken up into parts. These typically include an instructor led review of the previous class with some review questions for students followed by interspersing of segments involving 10-12 minute mini-lectures, chemical demonstrations and 4-5 minute worksheet-based group tasks and feedback. Such variation and pacing seems to be optimal for keeping students engaged in class (Bunce, Flens, & Neiles, 2010). In place of tutor-led problem solving, tutorials now are completely student-centred with all of the time given over to POGIL-style worksheets that are completed and reported in groups.

Our implementation of a POGIL-like approach has also been strongly influenced by a realisation of the responsibility of all first year units in developing academic skills (Arndell, Bridgeman, Goldsworthy, Taylor, Tzioumis, 2012; Kift, Nelson, & Clark, 2010) and the WAC philosophy discussed above. It has also been informed through our engagement with an expert in language learning and teaching (Zhang, Lidbury, Richardson, Yates, Gardiner, Bridgeman, Schulte, Rodger, & Mate, 2012). The latter work identified the significant role that difficulties with scientific language, nomenclature and symbolism play in preventing success across both home and international students. This paper discusses the use of 'Writing To Learn' activities as part of POGIL style classes in first and second year chemistry which seek to embed regular, informal writing tasks throughout the semester as a normal part of the students' learning.

Around 2000 students in semester 1 and around 1800 students in semester 2 take first year Chemistry units at The University of Sydney. These students come from every faculty in the university and a large number of degree programs. A significant number of these are international students or have English as their second language.

VERY SHORT WRITING TASKS IN THE LECTURE

In a chemistry lecture, there is often very little time for writing more than 2 – 3 sentences. In large classes, this may be exasperated by the need to keep the class on task and the very wide range of times it may take different students to write anything substantial. Many students have a tendency to use inflated or over-complicated language, perhaps in an attempt to write academically, whereas scientists usually value simple explanations and summaries.

Forcing students to commit their ideas to paper and to condense their thoughts in just 1 – 2 sentences can be hugely beneficial. Indeed, in some activities, students are limited to 140 characters (the limit commonly used by microblogging sites, such as Twitter). As described below, short writing tasks can be incorporated as stand-alone activities, as part of POGIL-style worksheets or included as part of the lecture notes. However implemented, they can be a valuable tool for engaging students, for helping them learn subject material and concepts, and for developing the habit and the skill of note taking.

(i) Writing to learn using worksheets in lectures

The worksheets used in the author's lectures are provided in hard copy to each student who attends. Based on the POGIL model (Moog et al., 2008), they follow a learning cycle (Abraham, 2005) to guide students through:

- an exploration phase in which students are given information or data and develop a hypothesis
- a concept invention phase in which new concepts are introduced based on this understanding, and
- an application phase in which these concepts are applied to new situations.

The students work on these tasks in groups. In our implementation, the exploration phase is often developed in a mini-lecture and in the lecture notes, to save time and to reduce photocopying costs. Both the concept invention and application phases may suit short writing tasks.

Each worksheet contains at least one very short writing task. Students are given a minute or so to write 1 or 2 sentences. These tasks are not assessed and are not marked by the instructor. As the motivation of the intervention is to improve students ability and willingness to use writing as a way of clarifying their own understand, peer and class sharing and feedback are used to keep students on task. After trials in individual lectures, in-class writing assignments have been used in each lecture for 3 years in a second semester, first year general chemistry unit aimed at students without high-school chemistry and for 2 years in a first semester, second year quantum chemistry and spectroscopy unit. In each case, some students are initially reluctant to engage with writing but participation grows steadily when the tasks are used regularly.

Such very short writing tasks can be used for situations where a short description or explanation in words would clarify or simplify the concept or would assist in knowledge retention. Examples include writing short summaries of concepts, descriptions of mathematical or graphical relationships, development of analogies from every-day life and prediction of behaviour. A few examples are briefly outlined below.

In a class on the concept of conjugate acids and bases, the mini-lecture segment consists of the standard Brønsted-Lowry definitions of an acid and base. On the worksheet, the students are given a couple of acid-base equilibria, such as those below, and are asked in their groups to identify the acid and base for the forward and reverse reactions.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$
$$HCN(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$$

Having done this, the students are asked to spot and discuss the relationship between the role of a species in the forward and the backward reaction: they discover the concept of conjugate acid-base pairs. To embed this newly invented concept, the students are asked to describe the general relationship they have deduced to each other. When they agree, each member of the group writes down the relationship in words – without chemical symbols or equations – in 1 or 2 sentences. A couple of these are then chosen randomly and shared and reviewed by the whole class.

This activity typically takes 4 – 5 minutes and involves argumentation verbal articulation and use of writing to force students to organise and express their understanding. Although less precise and technical than those in the lecture notes or in the textbook, the words used by students often contain contemporary jargon that may help other students understand. Definitions in lecture notes tend to invite being memorised rather than understood. Of course, the review session may also reveal misconceptions, which can then be tackled straight away.

Having discovered that water can act as both an acid and a base, the students are then asked on the worksheet to consider and predict what happens in a glass of water and a glass of ammonia. Alongside writing the relevant chemical equations, they are again set a short writing task of describing the chemical nature of water and ammonia.

The following classes build on these conceptual ideas using a more quantitative approach. Students calculated the pH of strong and weak acids with the aim of developing an understanding of the relationship between pH and the concentration and strength of the acid. There a number of language issues associated with this topic that lead to misconceptions: ‘strong’ and ‘weak’ are used to describe the extent of dissociation of the acid in solution and ‘concentrated’ and ‘dilute’ are used to describe how much acid is present. Thus, a beaker might contain a concentrated solution of a strong acid, a concentrated solution of a weak acid, a dilute solution of a strong acid or a dilute solution of a weak acid. The precise, technical definition of strong vs concentrated and weak vs dilute are clear to the expert but can be difficult to explain. At the end of the section, the students are thus asked to describe in one sentence what is present in each of these 4 solutions.

Perhaps surprisingly, writing tasks seem ideally suited to helping students develop their understanding and appreciation of quantum chemistry. Before their introduction, most lectures were very mathematical and abstract. In a couple of worksheets, students work out the energy levels of a particle in a box and on a ring. They are then asked to predict and then describe in words what happens to properties such as energy and position probability when the mass is large. In a following class, the students are asked to apply the particle in a box model to themselves trapped in the lecture theatre, and then commit to paper a couple of sentences describing their behaviour.

In a subsequent lecture on electronic spectroscopy, students are presented with the different ways in which energy can be lost from an electronically excited molecule. After labelling the different routes (such as fluorescence, phosphorescence and non-radiative decay) on a diagram, each group is asked to describe these in words. In small groups, they then produce a mini-story detailing the sequence and nature of the events.

(ii) Writing to learn by summarising topics

At the end of each section of a lecture or at the end, students are requested to briefly discuss the topics covered with their neighbours and to write a very brief summary of the general principals covered. In first year classes, students are asked to answer the question:

- What were the most important points made in today’s class?
- Such ‘one minute papers’ have been shown to enhance students’ marks and recall of material (Davis & Hult, 1997). Again, the activity is entirely informal and is not marked. Student participation is often enhanced, however, by asking a random group to report their response to the class. Every fortnight, or at the end of a part of the course, students are asked to agree an answer to a second question:
- What idea in this part of the course are you still unclear on?
- Responses to this question provide material on which to base revision or remedial material in future classes. A refinement of this activity is to ask students to write their own learning outcomes and then compare them to the ‘official’ one. This activity can encourage greater engagement with learning outcomes and help students organise their notes and revision.

(iii) Writing to learn using gapped lecture notes

Many of the activities discussed above are firmly embedded in the author’s own lectures and are beginning to be adopted by others in the School. However, in attempting to promote change, a more gentle break from fully teacher-centred lecturing is sometimes more effective. As noted in the Introduction, many lecturers use the tactic of leaving gaps in their handouts in an attempt to promote note taking and engagement. These gaps are often filled by the class copying from the lecturer's presentation with subsequent requests by students for the "full notes" to be posted online. Instead of simply providing the missing text for the class to copy, students can be asked to fill the gap in their *own* words by asking for a summary, a description of a mathematical relationship or their own example. Responsibility for provision of the "full notes" is passed to the students, whether they are present in the class or are studying at home.

VERY SHORT WRITING TASKS IN TUTORIALS

All tutorials in first year chemistry now use POGIL-style worksheets. The tutors, who consist of the relevant lecturers as well as postgraduate teaching fellows, act as facilitators and the vast majority of each tutorial class is given over to group work. Although writing assignments are not suited to every topic, the majority of the worksheets do include at least one very short writing task. Every first year chemistry student is thus writing regularly throughout each semester.

An early topic in most of our first semester units is the quantum mechanical description of the atom. Many students find this topic extremely abstract and unconvincing, when compared to the Bohr model of the atom they met at high school. The first task on the first worksheet of the semester therefore is for students to write down a summary of their understanding of this model. The worksheet then guides them through the structure of the Periodic Table, some of which match the Bohr model and some of which do not. Finally, the students are asked to discuss these features and to write down a critique of the evidence for the Bohr model being right or wrong according to the evidence in the Periodic Table. This worksheet is included as Appendix 1 to this paper.

Organic chemistry is highly symbolic, with the course of reactions shown using curly arrows to represent the flow of electrons. This device is extremely powerful in the hands of an expert, allowing for the prediction of reactions and the design of synthetic routes. Students introduced to curly arrows, however, often find it extremely difficult. In a couple of worksheets, the desired learning outcome is for students to be able to reproduce and understand the mechanism of the reaction of interest. In the first of these, students are now presented with the mechanism for nucleophilic substitution and are asked to describe the sequence of events implicit in this representation in 2 sentences. In the next tutorial, they first describe the reaction events in words and then transfer this to the curly arrow representation.

A couple of short writing tasks for lectures on acid-base chemistry were described above. These are built on in the tutorials through a more detailed set of guided calculations. These include students working through the calculation of the extent of dissociation of weak acids as a function of concentration. The groups then share their results to draw a graph showing the relationship that the calculations reveal. After having done this, the students discuss the relationship and describe it in 1 sentence. This part of the writing task thus requires them to be able to describe a mathematical relationship in words – something which many students are very poor at doing. These descriptions are shared and reviewed by the class.

The second and final part of the writing task asks them to describe in 1 sentence what happens to the *number* of ions that are present during the dilution. This is actually quite tricky, as students need to join together all of the information present: although the extent of dissociation increases, the dilution reduces the overall number of ions present. Having to write a description using words and no mathematical symbols forces the students to process the information at a much deeper level.

Getting students to commit their ideas through writing is a good way to identify and address misconceptions. One misconception that is particularly hard to shift is the relative strength of intermolecular forces. Many students arrive at university with a set idea that dispersion forces are very weak. In a worksheet devoted to developing understanding of the importance of hydrogen bonding, dipole-dipole and dispersion forces in the main group hydrides, students are given a number of pieces of evidence through graphs showing the variation in melting and boiling points down groups and across periods. For each piece of evidence, they are asked to interpret the data in terms of these forces and to write down their conclusions. Finally, they are asked to summarise the arguments and then argue which force is the strongest.

Valuing Writing
As noted several times above, expecting students to write regularly is key. It is vital to explain to students in the first few classes why writing tasks are being given and that writing clearly and concisely is a valuable generic attribute. As the types of assessments we use undoubtedly signal our values to students, it is important to include examination questions that draw on the writing tasks from classes. Thus, alongside conceptual multiple choice questions and problems to solve, our examinations include questions which require short written descriptions of concepts and explanations of phenomena.

CONCLUSIONS
Writing tasks are a valuable tool for active learning in lectures and tutorials. Writing promotes deeper learning and can develop critical thinking. Writing tasks help support the development of desirable graduate attributes, especially communication skills. Such development is the responsibility of each discipline and every level of a degree. Informal, very short writing tasks when integrated and given regularly promote engagement and understanding.

Some students are reluctant to write and it is important to incorporate such tasks consistently and in places where they genuinely assist learning. In unit of study surveys, students commented very favourably on the use and design of worksheets incorporating writing tasks. Examples of open response comments include:

- “The worksheets are a good approach to learning in lectures. Writing down my ideas really helped when I came to revise.”
- “We were encouraged to work together in each lecture with the worksheets. It is actually helpful to discuss and then write things down.”
- “Writing really helped cement ideas.”

The introduction of writing tasks in tutorials across all units has been accompanied by an increase in the student evaluation of graduate attribute development, from an average of 3.2 / 5 to an average of 3.6 / 5 across all units. However, other interventions have undoubtedly influenced this more, especially as the writing intervention has been deliberately presented to students as a device to improve learning rather than preparation for the workplace.

The underlying idea behind the use of writing is the belief that students learn chemical concepts most effectively when they are actively engaged in doing and communicating about them rather than passively rote-learning, listening and watching. Very short writing tasks are scalable to large and small classes, and are fully adaptable to other topics beyond introductory chemistry. They connect with a desire amongst students to be social and to learn from peers and help to ensure that classes are vibrant and engaging.

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APPENDIX 1

CHEM1405 Worksheet 1: Does Bohr's Model Explain the Periodic Table?

Model 1: Bohr's Atomic Model

Bohr's model is sometimes called a "planetary" model; protons and neutrons are found in a central nucleus and electrons are placed in orbits that circle around the nucleus at a specific distance.

Critical thinking questions

1. Discuss your understanding of Bohr's atomic model within your group. Summarise your discussion below in 2-3 grammatically correct sentences. (*Hint*: what are shells and how many electrons are allowed in each shell?)

2. Draw a diagram showing Bohr's model of the atoms below, showing as many relevant features as you can think of.

   (a) He   (b) Li   (c) Ne

   (d) *Ask your tutor for another example for you to work on and share with the class.*

3. What is the relationship between the number of electrons in a shell and the number of the shell? Write down this relationship in 1 sentence and read it out to your neighbour.

4. Share your ideas of Bohr's atomic model with the whole class.

Model 2: The Periodic Table

The figure below shows part of the Periodic Table in which the elements are placed together in *groups* (the columns) and *periods* (the rows).

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe

Critical thinking questions

1. Discuss any features and patterns you can see in the Periodic Table within your group. Summarise your discussion below in 2-3 grammatically correct sentences. (*Hint*: look for blocks of elements in each row).

2. What filling patterns can you identify in the Periodic Table? (Your tutor will have a copy of the whole Table if you want to extend your work.).

3. Can you relate these features and patterns to Bohr's atomic model? Summarise your discussion below in 2-3 grammatically correct sentences.

4. Are there any discrepancies between Bohr's model and the Periodic Table? Summarise your discussion below in 2-3 grammatically correct sentences. Read your sentence out to the rest of your table and ask them to comment on your arguments.